4.0 COMPONENT ANALYSIS

BACKGROUND

The Component Analysis Action Team (Component Analysis AT) is responsible for fostering collaboration between individual HCF component analysis efforts, with the overall goal of combining with the Instrumentation and Forced Response ATs to better determine alternating stresses to within 20%. The Component Analysis AT provides technical coordination and communication between active participants involved in HCF component analysis technologies. Annual technical workshops have been organized and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Component Analysis AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for component analysis projects, and coordinate with the TPT and IAP. The Chairman (or Co-Chair) of the Component Analysis AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis. This AT includes members from government agencies, industry, and universities who are actively involved in component analysis technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related projects.

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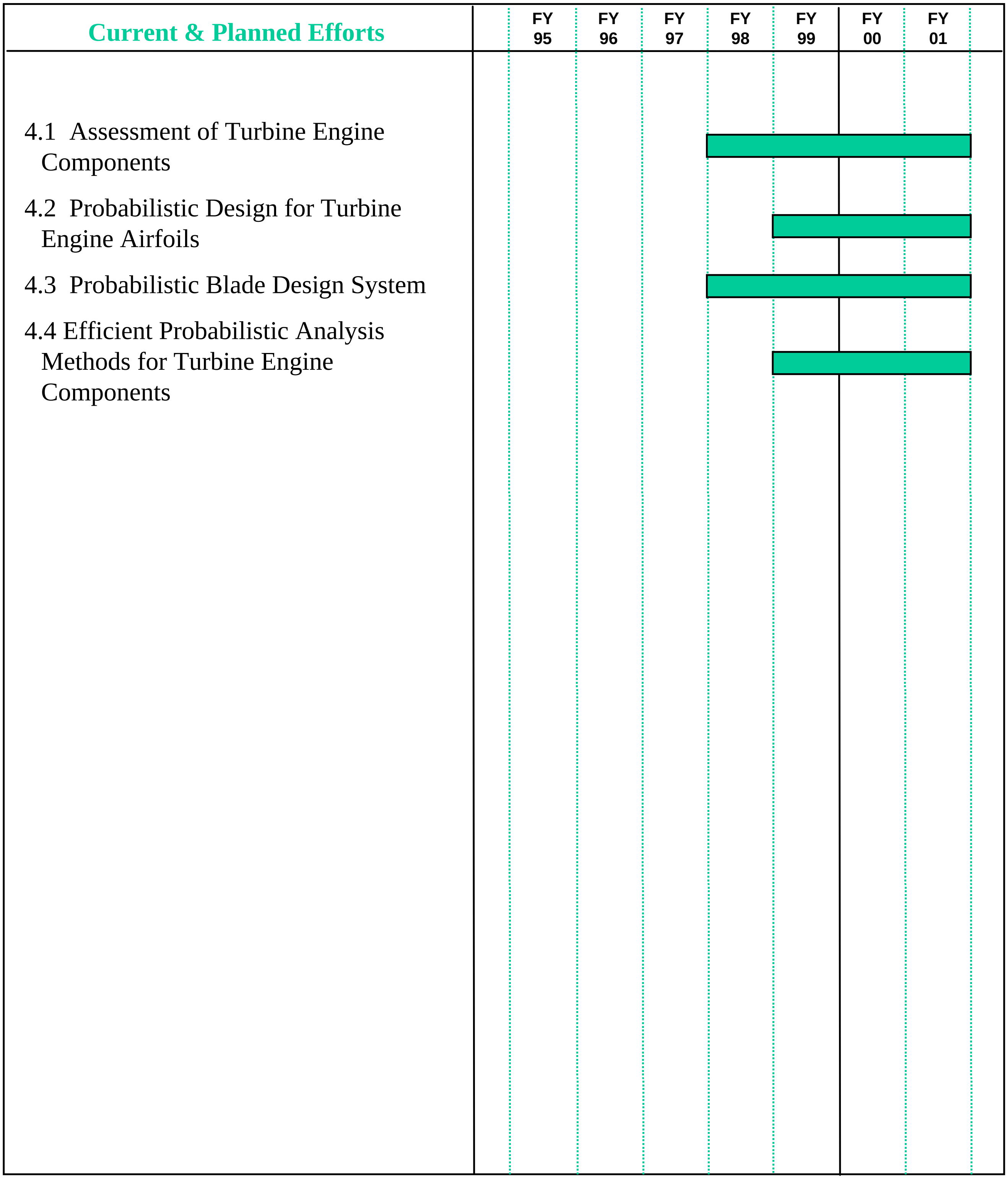
INTRODUCTION

The following pages summarize the schedules, backgrounds, and recent progress of the current and planned projects managed by this action team.

Component Analysis Schedule



4.1 Assessment of Turbine Engine Components
FY 98-01

Background: Current design practice for turbine engine components includes methods for modeling the structural behavior of complicated interfaces, such as bolted connections and snap rings. These interfaces are difficult to integrate into an overall structural model. The objective of this effort is to develop accurate and reliable methods and practices for modeling nonlinear interfaces. Both linear and nonlinear analysis techniques are required. In detailed stress and life prediction analysis, the analyst may need to consider the effects of pretension, contact, and friction, and a reliable nonlinear model of the connection is appropriate. For substructured analyses, and prediction of natural frequencies, the joint model must be linearized to be usable. The linearized model may contain some evidence of the nonlinearity, such as properties that depend upon preload.

To obtain the needed data, detailed finite element analyses (FEAs) of bolted connections are to be performed to determine effective properties, which are then to be used in component-level structural analysis. In general, the process of performing a detailed FEA involves the following steps:

A refined model of the joint is analyzed in detail, including the effect of pretensioning and contact. At several preload levels, several elementary loading conditions are analyzed to obtain effective stiffness characteristics for the joint. The resulting stiffness parameters may be used to define joint properties in a larger model. Once a solution has been obtained in the system-level model, stress information can be obtained for the joint based upon the original analysis of the joint model.

Figure 32 shows a finite element model of a joint between two compressor stages, and the detailed stress field in and around the bolted connection. This model is being used for validation of stress analyses performed using the simplified joint model, which is much smaller and may be analyzed with linear solution techniques.

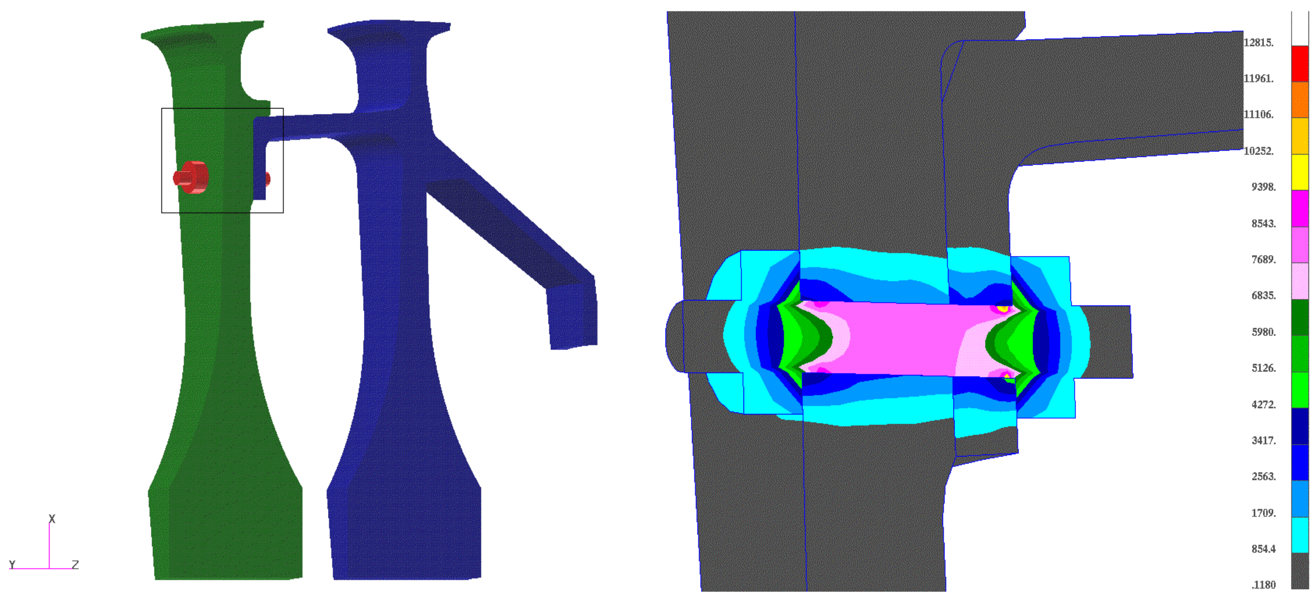


FIGURE 32. Finite Element Model of a Joint Between Two Compressor Stages

Recent Progress: Recent efforts have focused on performing detailed finite element analyses of bolted connections to determine effective properties, which are then used in component-level structural analysis. Investigations into the accuracy of commonly used finite element types for natural frequency prediction have been extended to curved and twisted shapes, for which analytical solutions are not available. An error estimation code has been developed, and presently is being used to correlate several error estimation methods with observed frequency errors in finite element meshes of varying refinement.

Participating Organizations: University of Dayton Research Institute

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4.2 Probabilistic Design for Turbine Engine Airfoils
FY 99-01

Background: The objective of this task is to develop a probabilistic design system (Fig. 33) that will integrate all the HCF technical areas and produce rigorous and efficient statistical methods for computational procedures, and that ultimately will improve blade life. Probabilistic models will be developed that incorporate refinements to the design process of gas turbine fan blades by the use of: (1) an efficient probabilistic framework for HCF predictions using advanced stochastic modeling concepts, (2) refined probabilistic modeling for complex space-time phenomena, (3) a probabilistic framework capable of handling highly nonlinear problems with a large number of variables and complex interactions, (4) an adaptive, multilevel, modularly-structured probabilistic implementation suitable for integration into industry's proprietary systems, and (5) an integrated probabilistic framework open to future technological developments.

Recent Progress: A contract with STI Technologies was awarded in May 1999. STI is currently planning for the stochastic modules and preparing for their verification. Preparation for such verification involves collaboration between STI and the four major engine companies, who will investigate the physics behind the stochastic distributions, prepare databases of major parameters, and subsequently undertake the verification studies. The major parameters involved will be selected from the results of a Delphi Study. This study will be conducted early in the project. It is anticipated that arrangements with subcontractors will be completed by mid-December 1999, after which the Delphi Study will follow. In addition, collaboration between STI and ARA has been initiated. Data relating to a bladed-disk arrangement has been provided by STI for the purpose of applying the code ProFES for prediction of failure probability.

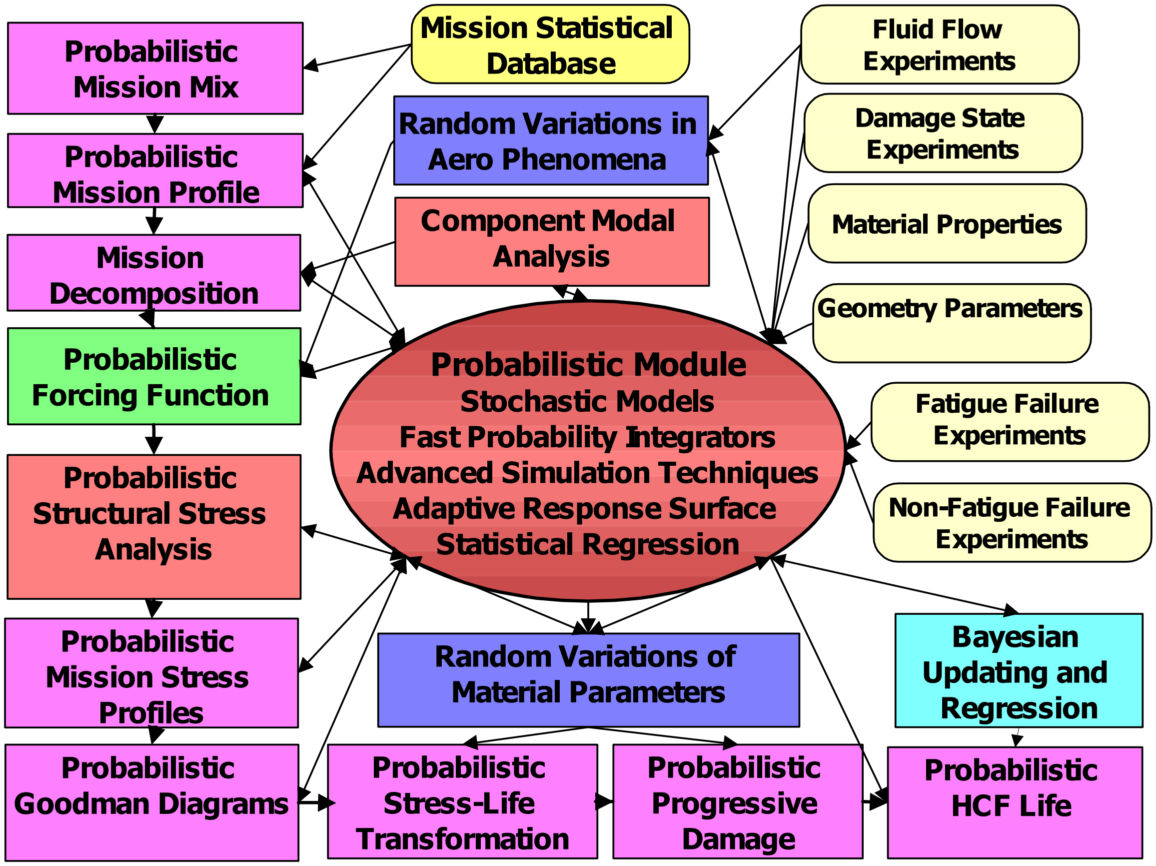

FIGURE 33. Probabilistic HCF Prediction System

Participating Organizations: Stress Technology Incorporated, General Electric, Pratt & Whitney, Allison Engine Co, Honeywell Engines and Systems, Virginia Polytechnic Institute.

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4.3 Probabilistic Blade Design System

FY 98-01

Background: Probabilistic analysis capabilities are being investigated in the areas of response variability due to blade mistuning, fracture screening, and the effects of closely spaced modes. Application of these techniques to several blades will provide guidance for the incorporation of such capability into a mainstream blade design system.

Recent Progress: Blade-to-blade response variability due to mistuning is being investigated using the REDUCE computer code. (See Sections 5.1.3 & 5.1.4 for a description of REDUCE). Initial studies for an example bladed disk have shown the sensitivity of resonant response to depend on the type of mode, with the most sensitive being system modes in regions where blade-alone modes cross disk-alone modes. Least sensitive are disk-alone modes with blade-alone modes being medium in sensitivity. Investigations are now proceeding to include analysis of existing military fan blisks and bladed disks. Blade response from light probe and strain gage data from engine tests is being assembled for comparison with the analytical predictions.

Previous work in the area of fracture screening analyzed failure probabilities of internal flaws in rotating parts. This effort extends that work to consider failure probabilities of randomly placed and randomly sized surface flaws caused by foreign object damage (FOD). The existing probabilistic fracture mechanics software is currently being enhanced for these types of damage. Application of the method is focusing on the F110 family of stage-1 fan blades. Previously existing sources of FOD data pertinent to these blades are being examined to provide indicators of FOD frequency of occurrence, its spatial distribution and geometric characterization, and failure consequences of the flaws. These sources include field inspection and failure inspection reports. Assessments of the failure probability will proceed based on these flaw distributions.

Participating Organizations: GE Aircraft Engines / Allison Advanced Development Company

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4.4 Efficient Probabilistic Analysis Methods for Turbine Engine Components

FY 99-01

Background: Efficient and accurate methods for the reliability analysis of large-scale engine component models are the main goals of the project. Response surface methods are applicable when the number of random variables is very small. For practical engine components, there are potentially dozens of uncertain variables, and the designers need to use robust techniques that can accurately predict the failure probability with a minimum number of simulations. Under this research effort, methods are being developed that use function approximations to reduce the computational cost of simulations.

Recent Progress: Recently, methods have been developed based on Fast Fourier Transformation (FFT) techniques for accurately predicting the failure probability for highly nonlinear limit-states and non-normal distributions. To validate the concepts, several highly nonlinear analytical functions and structures modeled with truss and plate members will be considered with normal and lognormal distributions. The results obtained by using FFT will be compared with the Monte Carlo simulations.

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4.5 Conclusion

The Component Analysis Action Team established a government/industry/university team to develop an HCF probabilistic design system that will integrate all the HCF technical areas, produce rigorous and efficient statistical methods for computational procedures, and improve blade life. The Team achieved agreement on the basic approach to probabilistic life-prediction system development. Efforts are underway with the lead integrating contractor and multiple engine companies. This team recently recognized successes achieved by the University of Dayton Research Institute in two areas: error estimation for finite element modeling, and interference fit modeling for finite elemental analysis.